to their length by use of the particular strategies described herein. Specifically, for nanotubes of different aspect ratio but having the same diameter, the velocities of the nanotubes scale approximately with the natural logarithm of the aspect ratio, which allows for sufficient separation in a process that allows for fractionation.

[0039] The preferred embodiment methods according to the present invention generally involve first forming a dispersion or solution of the population of carbon nanotubes to be separated. After suitably dispersing the nanotubes, an agent having particular density characteristics relative to the dispersed nanotubes is selected. Using that selected agent, an array of liquid layers is then formed in a suitable vessel. The selected agent is periodically referred to herein as a "density adjusting" agent. Generally, a first layer of the dispersed nanotubes to be separated by length, is formed in the vessel. This first layer is periodically referred to herein as an "injection" layer. Next, one or more liquid layers having densities less than that of the injection layer are then formed above the injection layer. The one or more lighter density layers comprises the selected agent having the desired density characteristics and varying amounts of one or more liquids. The proportions of the density adjusting agent and the one or more liquids are selected so as to achieve a desired density for the particular layer. The one or more liquids preferably exhibit densities less than that of the density adjusting agent. It is also contemplated that an optional upper layer may be formed comprising the one or more liquids and which is free of the density adjusting agent. All of the layers between the first (or injection) layer and the upper layer are generally referred to herein as "race layers," since those are the layers through which the dispersed nanotubes migrate during a centrifugation operation. The layered array may also include one or more relatively dense layers under the injection layer. These underlayers preferably comprise relatively high concentrations of the density adjusting agent and lesser amounts of the one or more liquids used in the race layers. After formation of the layered array in the vessel, the vessel and its contents are subjected to a centrifugation operation. Centrifugation is performed for a period of time sufficient to allow two or more fractions to form in the race layers. Each resulting fraction contains carbon nanotubes having an average length that is different than the average lengths of carbon nanotubes contained in other fractions in the race layers. As explained herein, generally, carbon nanotubes having longer lengths are present in upper residing fractions, while shorter length carbon nanotubes are present in fractions closer to the first layer.

[0040] Each of these aspects and operations are now described in greater detail. After obtaining a collection or sample of carbon nanotubes which are to be separated by length, the collection of nanotubes is dispersed in a liquid such that ideally all of the carbon nanotubes are individually dispersed in the liquid. The liquid may be water or any other vehicle so long as the nanotubes can be sufficiently solubilized so that they are not in a bundled or otherwise agglomerated state. One or more surfactants and/or other additives may be used to promote such dispersion of the carbon nanotubes.

[0041] Dispersion of the carbon nanotubes in a liquid can be greatly facilitated by subjecting the nanotubes in liquid to sonication for a sufficient period of time so that all, or at least a relatively high proportion of the carbon nanotubes are individually dispersed in the liquid. After sonication, it is preferred to remove carbonaceous and metallic impurities. This can be readily performed by subjecting the sonicated sample to a centrifugation operation that pellets these impurities. The supernatant primarily contains individually dispersed carbon nanotubes.

[0042] Next, one or more density adjusted liquids for use as the race layers are prepared or otherwise obtained. As previously explained, the race layers are deposited above the layer containing the sample of carbon nanotubes to be separated, i.e. the injection layer. The race layers comprise a particular agent, which may be a liquid, generally referred to herein as a density adjusting agent having certain density characteristics relative to the dispersed nanotubes. Generally, the race layers comprise varying proportions of the density adjusting agent and one or more liquids selected so as to achieve a desired density for the particular race layer. The race layers may also comprise amounts of other additives described in greater detail herein. The number of race layers may vary depending upon the particular application and degree of separation desired, among a host of other factors. However, for many applications it is sufficient that a single race layer be used.

[0043] After formation of the various density adjusted liquids, an array of layers is formed or otherwise deposited in a suitable vessel. The vessel can be nearly any type of vessel appropriate for centrifugation. Preferably, one or more relatively dense underlayers are deposited in the vessel. The underlayers can be formed from liquids comprising a relatively high concentration of the density adjusting agent. On top of these, an injection layer containing a relatively high proportion of carbon nanotubes to be separated is then deposited. Next, the race layers are deposited on the injection layer. For example, for a layered array having three race layers, a vessel containing an injection layer and an optional underlayer is provided. A first race layer having a density less than that of the injection layer but greater than the densities of the other two race layers is deposited in the vessel on the injection layer. This first race layer comprises an amount of the density adjusting agent and another liquid. A second race layer is deposited in the vessel on the first race layer, and also comprises an amount of the density adjusting agent and the other liquid. The proportions of these components are selected so that the second race layer has a density less than that of the first race layer. A third race layer is deposited on the second race layer. The third race layer comprises an amount of the density adjusting agent and the other liquid. The proportions of these components are selected so that the third race layer has a density less than that of the second race layer. An optional upper layer may be deposited on the uppermost, e.g. third, race layer. It will be appreciated that the present invention includes layered arrays having a different number of race layers, such as one, two, or more than three race layers. These aspects are described in greater detail herein.

[0044] The vessel containing the resulting array of layers is then subjected to a centrifugation operation. Preferably centrifugation is performed for a period of time sufficient for the carbon nanotubes in the injection layer to migrate into the race layers, and thus form the noted fractions containing various populations of the nanotubes differing by length.

[0045] As noted, one or more surfactants can be used to assist in the dispersion of the nanotubes. Also, one or more surfactants can be used in the preparation of the density adjusted race layers. A surfactant is not intrinsically necessary to the separation process, but in practice is preferred to achieve robust individualization of the SWCNTs. Sodium